High-Speed Jet Noise Reduction
NASA Perspective

presented to

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Reducing Naval Aircraft Noise

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History Shows The Problem Is Difficult To Solve

Good News: High performance military aircraft noise is dominated by a single source called "jet noise" (commercial aircraft have multiple sources)

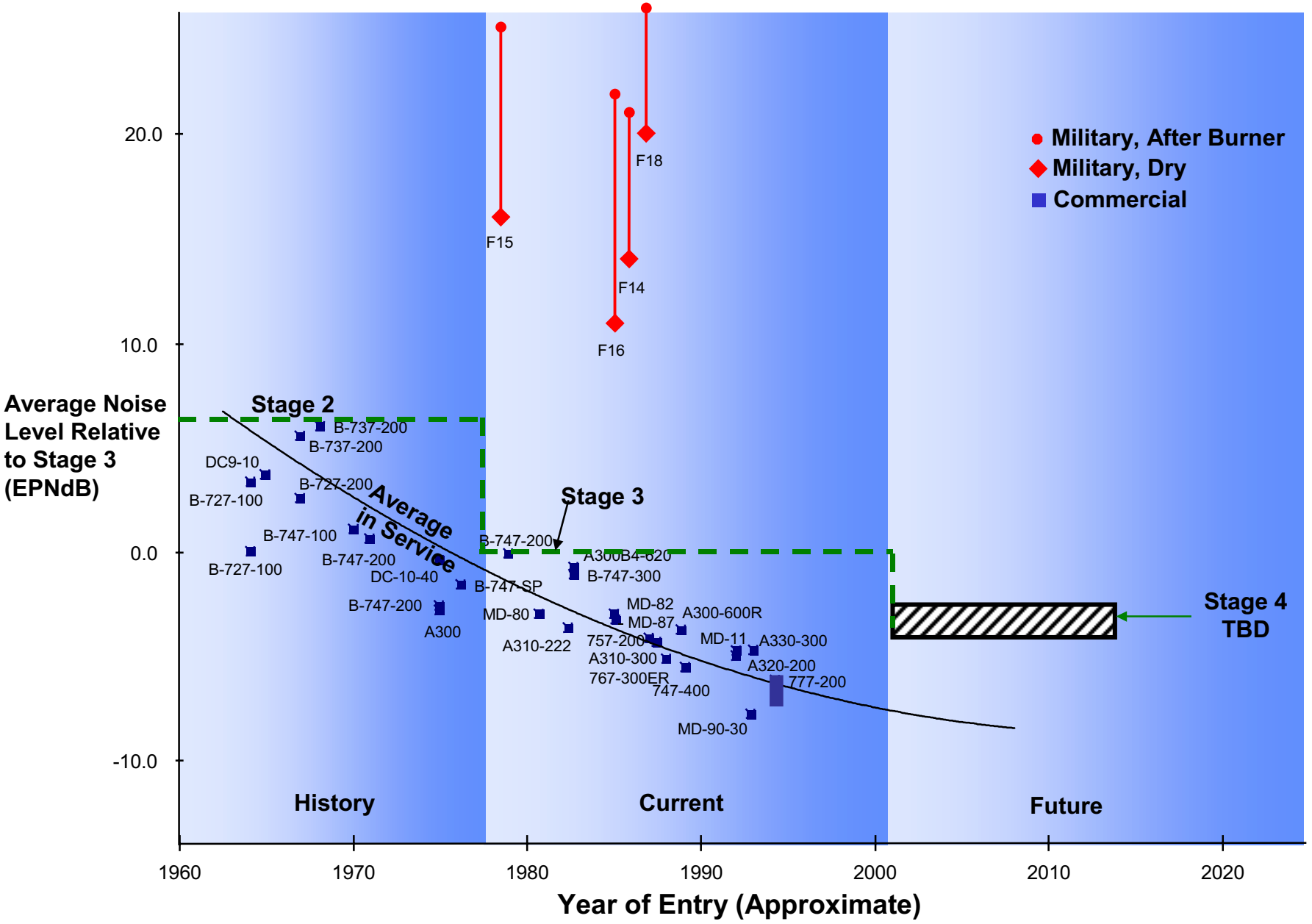
Bad News: This source has been the subject of research for the past 50 years and progress has been incremental.

- Major jet noise reduction has been achieved through changing the cycle of the engine to reduce the jet exit velocity.

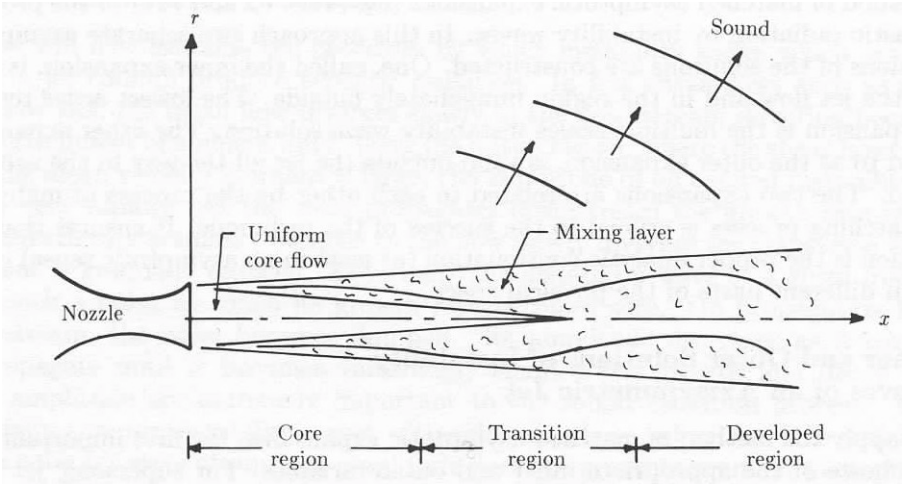
- Smaller reductions (a few EPNdB) have been achieved using suppression devices like mixing enhancement, acoustic liners.

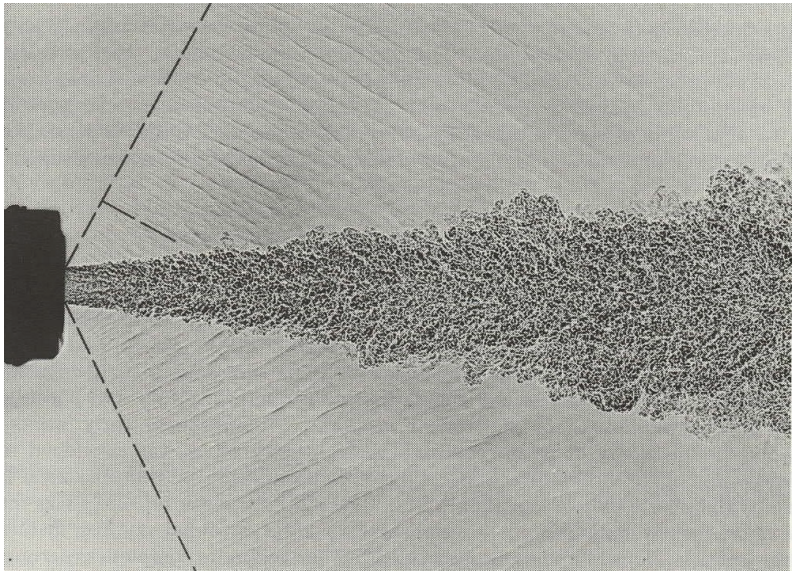
- Significant jet noise reduction without any performance loss is probably not possible!

Aircraft Noise Trends



Supersonic Jet Noise Sources





- **Turbulent Jet Mixing**
- **Broadband Shock Noise**
- **Screech**

Tam, C.K.W., Directional Acoustic Radiation From a Supersonic Je t Generated by Shear Layer Instability, *Journal of Fluid Mechanics*, Vol. 46, Pt. 4, Apr. 27, 1971, pp. 757-768.

Recent NASA Noise Reduction Research Programs

High Speed Research (HSR) Program

- 1990 - 1999
- ~$75M for noise
- Focused research on specific engine & mission (mixed-flow turbofan)

Advanced Subsonic Technology (AST) Noise Reduction Program

- 1993 - 2001
- $214M total, $154M for engine-related work
- Applied research for commercial turbofan engines with emphasis on fan and jet noise

Aerospace Propulsion and Power (Base) Program - Fundamental Noise

- 1999 - present
- $2M (1999), $600K (2000 and beyond)
- Fundamental research for fan and jet noise (subsonic & supersonic)

Quiet Aircraft Technology (QAT) Program

- Planned for 2001 - 2005
- $45M for Engine Systems Noise Reduction
- Research for new subsonic commercial engines to meet aggressive 10 dB and 20 dB noise reduction goals (relative to 1997 best-in-fleet technology)

Noise research for subsonic applications outpaces supersonic work by a large margin!

Highlights From NASA's HSR Program

Noise research focused on improving low bypass ratio turbofans with variable geometry mixer-ejector nozzles

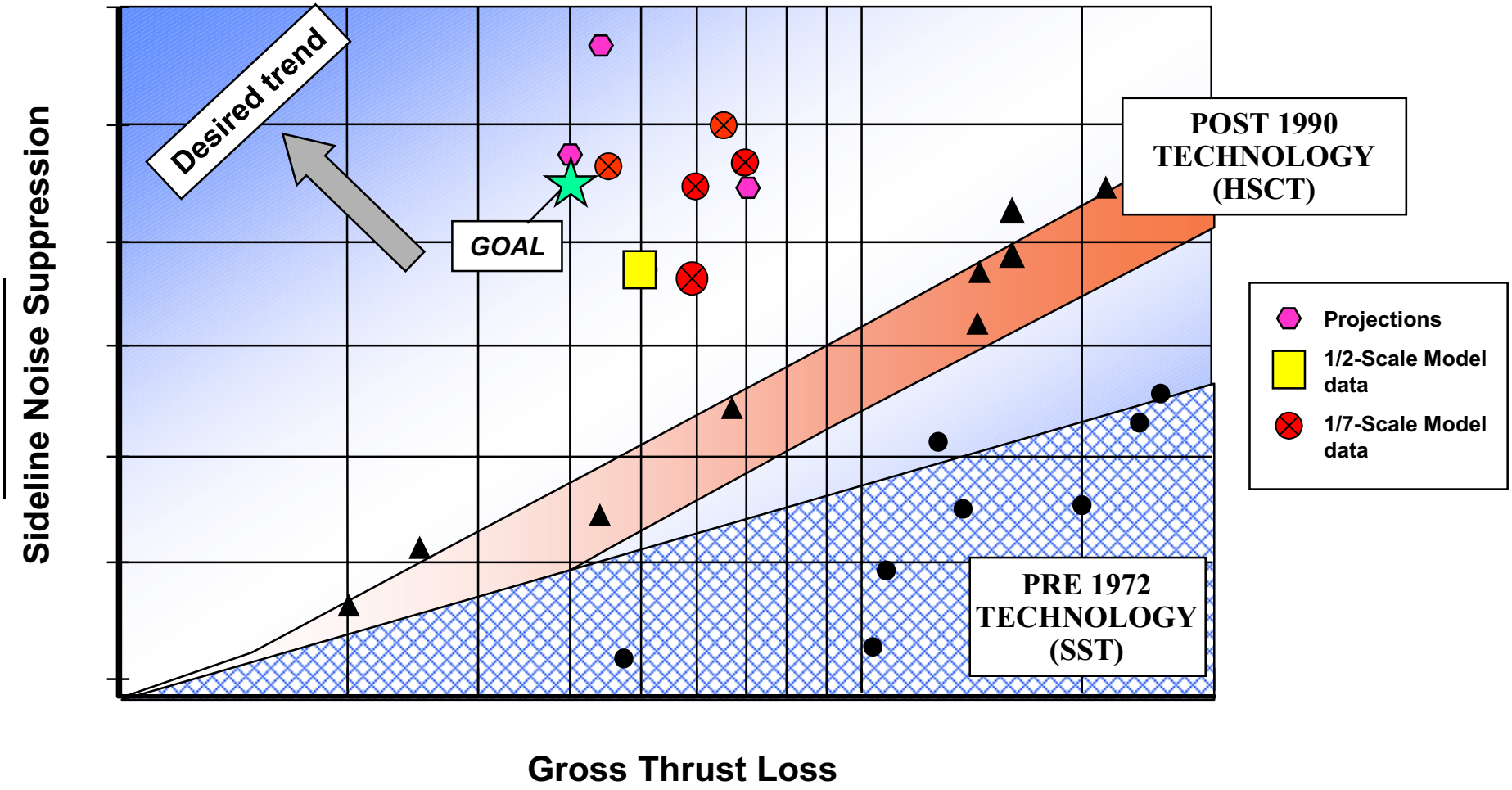
- **Mixer on primary flow reduces low frequency jet noise**
- **Acoustic liners absorb high frequency noise**
- **Fan inlet noise issue during approach, addressed through improved design**

Major Technology Improvements

- **Better mixer designs aided by 3-D CFD (reduced thrust loss)**
- **Improved acoustic liners (higher temperature, lower weight)**
- **Technology available to provide engine that can meet commercial certification requirements (Stage III with ~2-4 dB margin)**
- **Improved materials technology beat original engine weight goals**

High-Speed Civil Transport Jet Noise

Model Test Data Projections

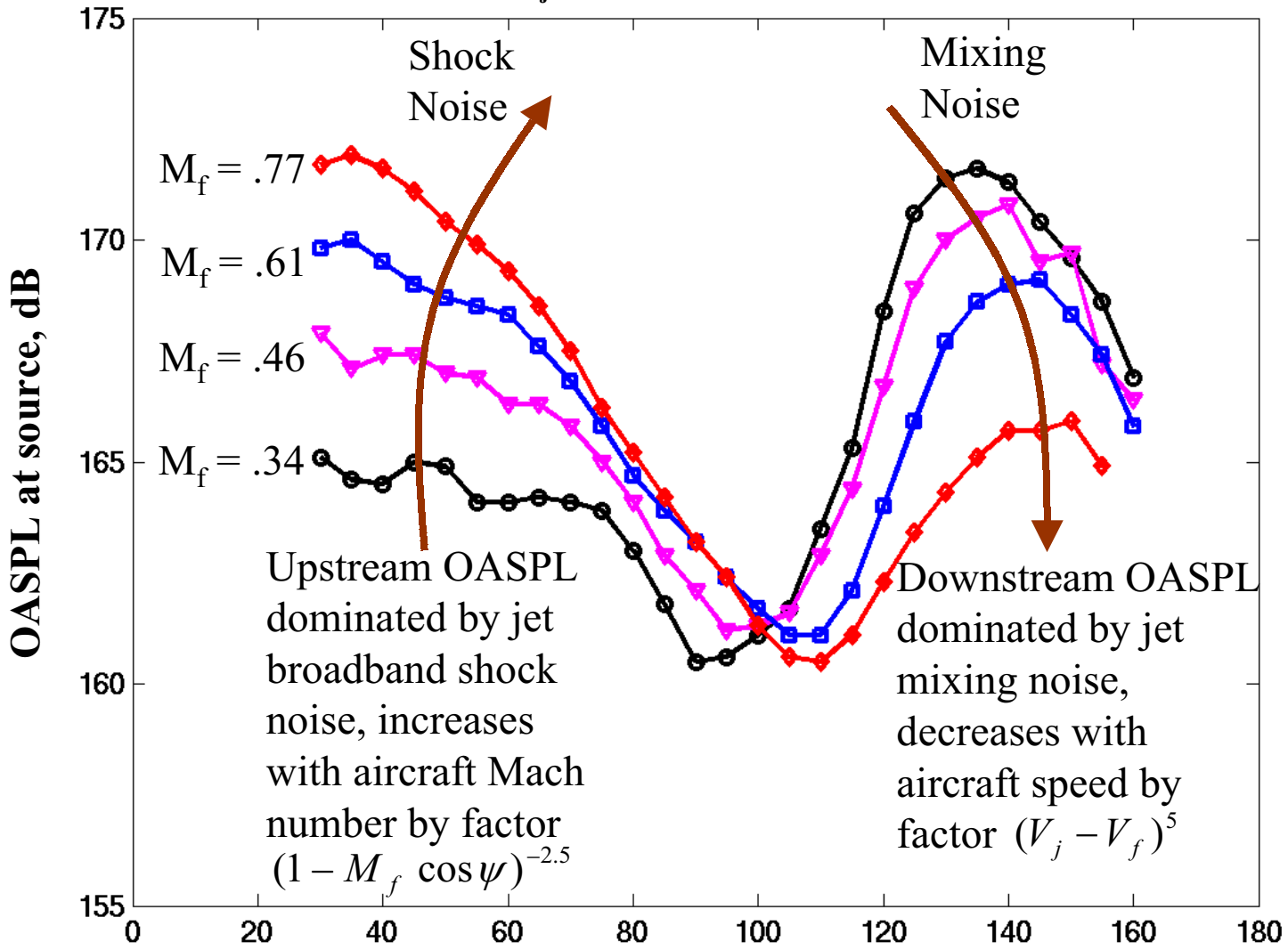


NASA Dryden Flight Research Center Photo Collection
http://www.dfrc.nasa.gov/gallery/photo/index.html
NASA Photo: EC98-44511-1 Date: 14 Apr 1998

F-15 ACTIVE in flight

F-15 ACTIVE ACOUSTIC FLIGHT TEST
EFFECTS OF FLIGHT SPEED ON JET NOISE

Fully expanded Mach number M_j = 1.45 Nozzle exit Mach number M_e = 1.73



From T. Norum, NASA Langley Research Center

Highlights From NASA's AST Program
(Engine Only)

Engine noise research focused on improving commercial turbofan engines

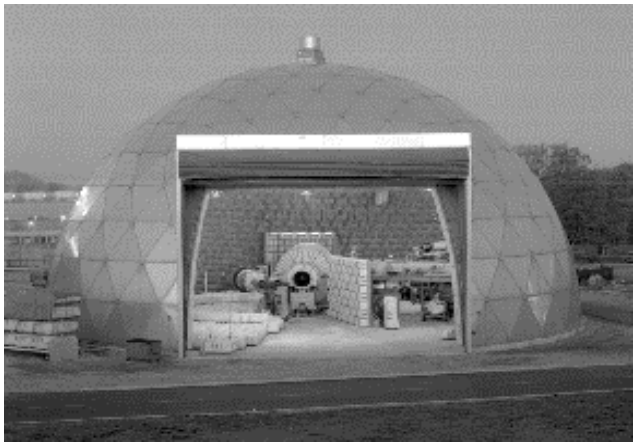
- 8 dB engine noise reduction relative to 1992 technology
- Emphasis on fan/jet noise source reduction, advanced nacelles/liners
- Met goals using combinations of engine cycle changes (lower fan speeds & jet exit velocities), improved low-noise design technology

Major Technology Improvements

- Ultra-High Bypass ratio engines (10-13) to reduce fan and jet noise
- Swept/Leaned stators to reduce fan noise
- Scarfed Inlets with advanced acoustic liners to reduce fan inlet noise
- Chevrons/Tabs on fan and core nozzles to reduce jet noise
- Active Noise Control of fan noise

AST Noise Reduction Program

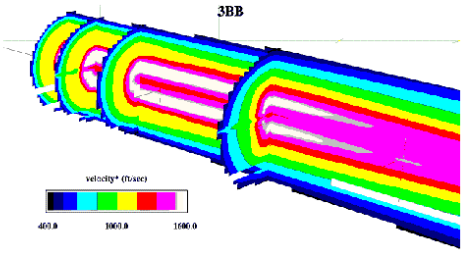
NASA/GE/P&W Separate Flow Nozzle Test



NASA Glenn Aeroacoustics Propulsion Laboratory

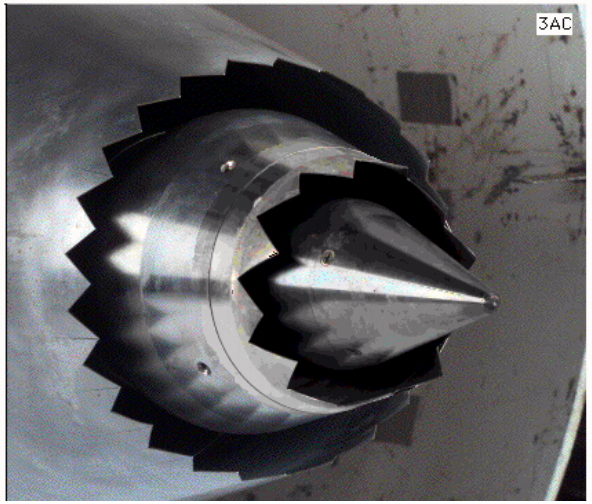
Impact: 3 EPNdB jet noise reduction, less than 0.25% thrust loss

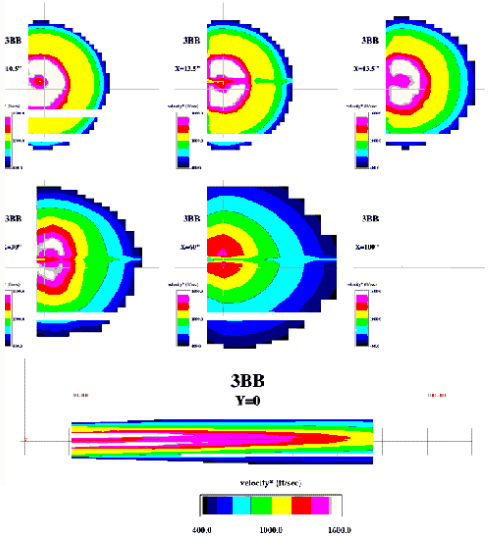
Flow Field Measurements



NOZZLES OF THE FUTURE:

Fan Chevrons with Core Alternating Chevrons





Highlights From NASA's Base Program

Noise research focused on fundamental aeroacoustics (started in 1999)

- **Application of new measurement methods to fan/jet flows (phased arrays, particle image velocimetry, etc)**
- **Fan and jet noise prediction using Computational AeroAcoustics (CAA)**
- **Will study supersonic jet noise source mechanisms**

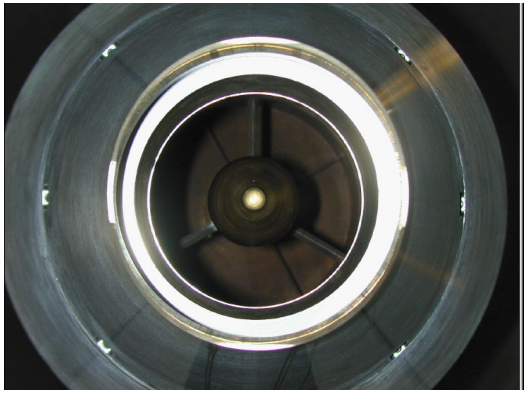
Major Technology Improvements (so far)

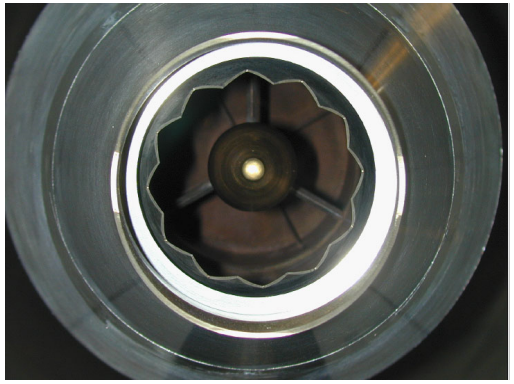
- **2-3 EPNdB jet noise reduction using chevron nozzles for a turbojet (extension of AST Program technology)**

Aerospace Propulsion and Power Program (Base)

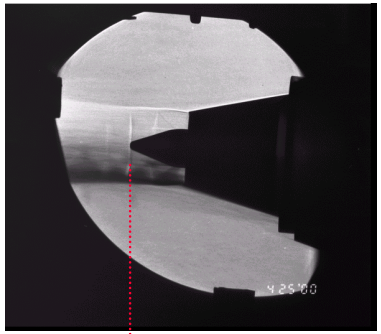
Turbojet Noise Reduction Using Chevron Nozzles

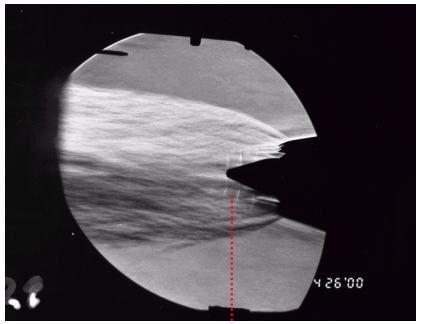
Baseline Nozzle **Chevron Nozzle**





Nozzles viewed from aft looking upstream





Schlieren Images

Infra-Red Signatures

NASA Lear 25 Flight Demonstration of Turbojet Noise Reduction

Objectives

- Confirm model scale test results
- Determine flight effects of installed chevron nozzle
- Investigate chevron nozzles for supersonic jet exit velocities

6 and 12 Point Chevron Nozzles

Approach

- Completed model scale acoustic and performance tests
- Demonstrated 3 EPNdB jet noise reduction with 0.5% thrust loss
- Flight test in March 2001 on Learjet 25 with CJ610-6 engines showed ~2 EPNdB jet noise reduction

(Show 6:30 minute video)

Realistic Expectations

- **With history as a guide, don't expect this problem to be solved soon.**
- **High performance aircraft cannot rely on engine cycle benefits the way commercial aircraft have met large noise reduction targets.**
- **Commercial aircraft have benefited from sustained noise reduction research. This has not been done for high performance aircraft engines, which means the foundation for this research still needs to be developed.**
- **Small reductions in jet noise (a few EPNdB) are expected to be possible with small performance penalties (< 0.5%). Retrofitable solutions may be possible.**
- **Large reductions in noise will require a long-term research commitment and consideration for noise during initial design of engine.**

Recommendations

Community Noise

- **Perform noise impact studies for several air bases using commercial aircraft noise abatement procedures to quantify the noise reduction possible without modifications to aircraft.**

- **Test passive mixing devices like chevron nozzles for higher jet velocities (may provide 2-3 EPNdB jet noise reduction without major changes to engines).**

- **Initiate long-term research program for high-speed jet noise that includes both experimental and analytical studies of novel noise reduction concepts**

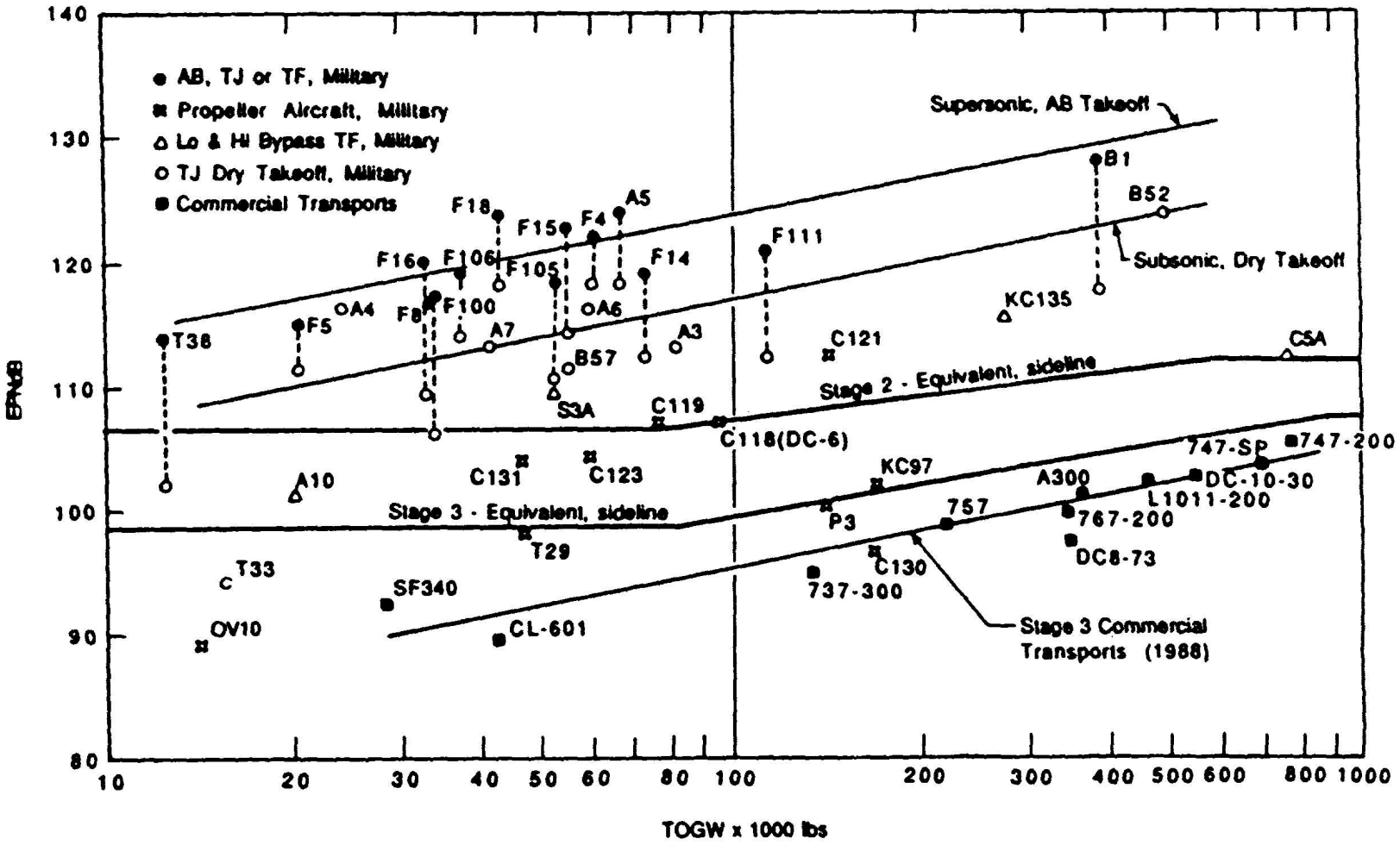
Near Field Noise

- **Source noise reduction helps, but will not solve ground crew noise problems (need considerably more noise reduction than a few dB)**

- **Will need to develop technologies for improved hearing protection**

(Back-Up Slides)

Effective Perceived Noise Level, EPNdB - 1000 ft, Takeoff power



Pinker, R.A., "A Brief Review of the Source Noise Technology Applicable to Fixed-Wing Military Aircraft", AGARD-CP-512, Combat Aircraft Noise, 1991)